Mutah University

College of Graduate Studies

Improved Localization Technique In Wireless Sensor Networks

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Improved Localization Technique In Wireless Sensor Networks

استكمالاً لمتطلبات الحصول على درجة الماجستير في **هندسة اتصالات.**

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DEDICATION

This thesis is dedicated to my father, who taught me that the best kind of knowledge to have is that which is learned for its own sake, it is also dedicated to my mother, who taught me that even the largest task can be accomplished if is done one step at a time. It also dedicated to my lovely wife who always supports me and care about raising my children.

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List of Abbreviation

AES	Advanced Encryption Standard
AoA	Angle of Arrival
AODV	Ad Hoc On-Demand Distance Vector
AP	Access Point
BSS	Basic Service Set
CLA	Centroid Localization Algorithm
DLL	Data Link Layer
DS	Distribution System
DV	Distance Vector
ESS	Extended Service Set
GPS	Global Position System
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IPSO	Internet Protocol of Smart Objects
MAC	Medium Access Control
MEMS	Micro Electro Mechanical System
OSI	Open Systems Interconnection
PHY	Physical Layer
RF	Radio Frequency
RSSI	Received Signal Strength Indicator
SNMP	Simple Network Management Protocol
TDoA	Time Difference of Arrival
ToA	Time of Arrival
ToF	Time of Flight
UTM	Universal Transverse Mercator
Wi-Fi	Wireless Fidelity
WLAN	Wireless Local Area Network
WPAN	Wireless Personal Area Network
WSN	Wireless Sensor Network

Abstract

Kazem Mohammed Alkhayyat

Mutah University, 2016

Improved Localization Technique In Wireless Sensor Networks

Many localization techniques in wireless sensor networks (WSN) have been investigated recently. These techniques were usually aimed to how locate unknown nodes or how to improve performance of localization. In this thesis an improved localization algorithm depend on range-free technique in (WSN) using a mobile anchor node which is equipped with GPS receiver to obtain its position. The mobile anchor node moves around sensing field with certain trajectory starting form certain point out of the sensing filed to a destination point with constant speed broadcasting beacon messages with certain radius including its location information. Each stationary sensor node takes information and calculates its location by computing the intersection area for four beacon nodes using centroid algorithm in its communication area. And whenever the intersectional area for four beacon nodes decreased the localization error (m) reduced. After the first round of localization, unknown sensor nodes can compute their locations with help of localized sensor nodes. A mathematical model was introduced and analyzed. MATLAB simulation results demonstrated that the accuracy of the proposed localization technique using mobile anchor node is better than the other techniques.

Keywords: Range-free technique, localization, centroid algorithm.

الملخص

كاظم محمد الخياط

جامعة مؤتة، 2016

تقنية محسنة لتحديد الموقع في شبكات الإستشعار اللاسلكية

طرحت عدة تقنيات لتحديد الموقع في شبكات الإستشعار اللاسلكية حديثا. تهدف هذه التقنيات عادة الى كيفية تحديد موقع العقدة غير المعروفة أو كيفية تحسين طريقة تحديد الموقع. في هذه الاطروحة تم إقتراح خوارزمية محسنة لتحديد الموقع تعتمد على تقنية (range-free) في شبكات الإستشعار الاسلكية بإستخدام عقدة متحركة مزودة بجهاز لتحديد موقعها. تقوم العقدة المتحركة بالتحرك حول مجال الإستشعار من نقطة بداية خارج مجال الإستشعار بإتجاه النقطة المحددة وبسرعه ثابتة، حيث تقوم ببث رسائل المعلومات عن موقعها ضمن نصف قطر محدد. كل نقطة استشعار ثابتة تأخذ المعلومات و تحسب موقعها من خلال حساب منطقة تقاطع لأربعة نقاط معرفة بإستخدام خوارزمية التوسيط من منطقة الاتصال.وأن كلما قلة منطقة التقاطع للعقد الأربعة تقل نسبة الخطأ في تحديد الموقع بالمتر. بعد نهاية الجولة الأولى لتحديد الموقع، تتمكن عقد الاستشعار المجهولة بحساب موقعها بمساعدة من عقد الإستشعار المعلومة. تم تقديم نموذج رياضي وتحليله. وأظهرت نتائج برنامج المحاكاة (MATLAB) أن دقة تقنية تحديد الموقع أفضل من التقنيات الأخرى التي تستخدم العقدة المتحركة.

الكلمات المفتاحية: خوارزمية التوسيط، تحديد الموقع، تقنية النطاق الحر

Chapter 1
Applications and Standard

1.1 Background

Sensors in the natural world include those which equip us with our five senses – sight, hearing, smell, taste and touch. These convert the various and diverse inputs to electrochemical signals that can be used to inform or control any living organism. In a similar way, in man-made devices, sensors are also used to measure various stimuli. The purpose of a sensor is to respond to some kind of a physical input (stimulus) and convert it into an electrical signal that is compatible with electronic circuits. [Graham Brooker (2007)].

There are many types of sensors which differ from each other in terms of their shape and the way they work. All sensors may be of two kinds: a passive and active. [Graham Brooker (2007)].

1.1.1 Passive sensors: Most of the passive sensors are direct sensors, which do not need any additional power source and directly generate an electrical signal in response to an external stimulus. The input stimulus energy is converted by the sensor into an output signal. Typical examples include thermocouples, photodiode and piezoelectric sensors as shown in Figure (1).

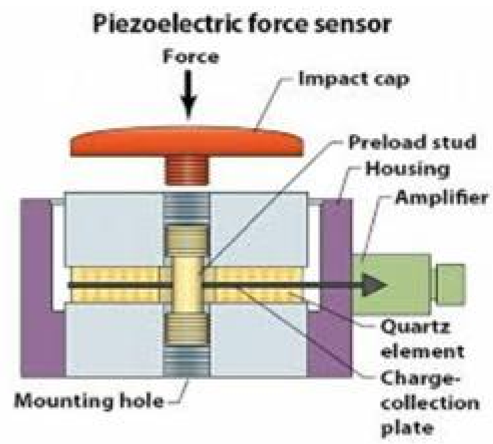

Figure 1 Piezoelectric sensor strictures [www.machinedesigne.com].

1.1.2 Active sensors: An external power is required for their operation, which is called an excitation signal. That signal is modified by the sensor to produce the output signal. The active sensors sometimes are called parametric because their own properties change in response to an external effect and these properties can be subsequently converted into electrical signals. We could say that the sensor parameter modulates the excitation signal and that modulation carries information of measured value. For example, a thermistor is a temperature sensitive resistor. It does not

generate any electric signal but by passing an electric current through it (excitation signal) its resistance can be measured by detecting variations in current or voltage across the thermistor as shown in Figure (2). [Gerald Recktenwald (2011)].

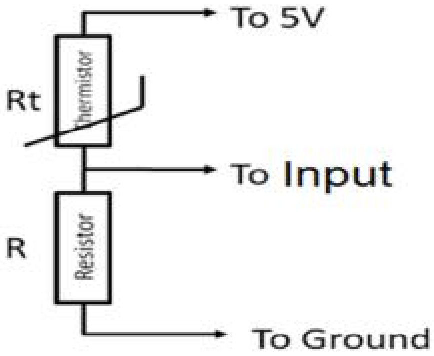

Figure 2 A thermistor [Gerald Recktenwald (2011)].

These variations are presented in (ohms) which directly relate to temperature through a known transfer function as shown in Figure (3).

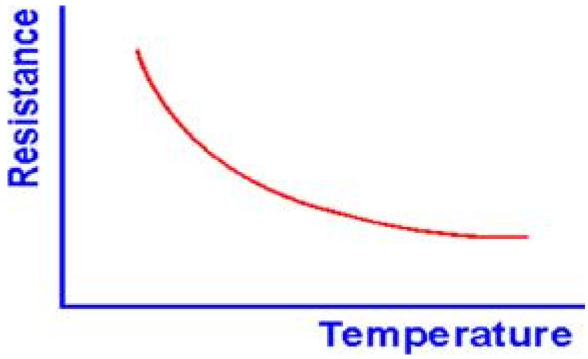

Figure 3 Resistance and temperature relationship [Gerald Recktenwald (2011)].

1.1.3 Smart Sensor

Wireless Sensor Networks have great worldwide attention in the recent year, especially with the proliferation in Micro- Electro-Mechanical-System (MEMS) technology which has contributed and developed of smart sensor. The most important properties. [Elmenreich W(2006)]:

1. Higher reliability.
2. Lower cost.
3. Electronic data storage.
4. Auto correction.
5. Ability to interface with different types of sensors.

1.1.4 Sensor Systems

Sensors cannot be operated in isolation as they are always part of a larger system, where other transducers may be included, sensors can share information with their neighbors and also with the user via a processing unit (sink). Sensor can be grouped to do some particular task or multiple tasks. A network of sensors called Wireless Sensor Network (WSN). [Graham Brooker (2007)].

A Wireless Sensor Network is a self-configuring network of small sensor nodes communicating among themselves using radio signals over maximum distance of around 100 m (at 2.4Ghz) and are deployed in quantity to sense and monitor. WSN has a wide range of potential applications, in industry, science, transportation, civil infrastructure, health and security. [Graham Brooker (2007)].

1.1.5 Advantages of WSN

1. Avoids a lot of wirings.
2. Can communicate with new devices any time.
3. Flexible to go through physical partitions.
4. It can be accessed through a centralized monitor.
5. Infrastructure.

1.1.6 Disadvantages of WSN

1. Comparatively low speed of communication.
2. Gets distracted by various elements.
3. Costly in a large area.
4. Life time.

1.2 Problem statement

A number of new conceptual problems such as location are posed by the challenges in Wireless Sensor Networks (WSNs). Substantial nodes are deployed randomly over the entire desired area of sensing regions for different nodes. There are several existing models of sensor behavior, each with varying degrees of complexity. However, most models share one thing in common; their sensing ability is directly dependent on distance. Therefore, in this thesis, an improved localization algorithm is found for WSN using a mobile anchor node with a Global Positioning System (GPS) to obtain its position and share the position with unknown nodes, to calculate its location and to find the suitable trajectory to cover most of the sensing field with low localization error. The performance of the proposed algorithm is evaluated and compared with the performance of the centroid algorithm using MATLAB.

1.3 Related works

Many researchers proposed several techniques for node localization in wireless sensor networks. Based on whether accurate ranging is required, there are generally two types of techniques: range-based and range-free. [HU Juan (2014)], [Linqing GUI (2013)].

1.3.1 Range-based technique

Firstly, one must precisely measure the range information (distance or angle) between the concerned equipment, and then calculate the desired position based on trilateration or triangulation approaches. The ranging techniques typically use the following: Received Signal Strength Indicator (RSSI), Time of Flight (TOF), Angle of Arrival (AOA) and the most well-known range-based technique using TOF or TDOA (Time Difference of Arrival).

The research of HU Juan and JIANG Minlan "An improve Node Localization Algorithm in Wireless Sensor Network" in 2014 discussed one approach of the range-based technique by improving the DV-Hop algorithm to handle low position accuracy in WSN. DV-Hop uses the principle of distance vector routing and GPS. The algorithm can be divided into four stages. [HU Juan (2014)]:

1. Calculates the minimum hops between anchor nodes and estimate the average distance per hop.
2. Calculates the minimum hops between unknown nodes and anchor nodes.
3. Calculates the distance between unknown nodes and anchor nodes. The product of minimum hop-size and average distances per-hop replace the distance of the unknown nodes and anchor nodes.
4. Calculates the coordinate of unknown nodes positioning Coordinate the least squares algorithm for unknown nodes.

1.3.2 Range-free technique

While the range-based scheme uses the distance or angle between nodes, the range-free scheme uses connectivity information between nodes. In this scheme, normal nodes first gather the connectivity information as well as the positions of anchors, and then calculate their own positions. [Linqing GUI (2013)].

The research of Baoli Zhang, Fengqi Yu and Zusheng Zhang "An Improved Localization Algorithm for Wireless Sensor Network Using a Mobile Anchor Node" in 2009 discussed one approach of range-free technique by using the mobile anchor node, which is equipped with a GPS receiver to obtain its position, the mobile anchor node moves around

in a sensor field to broadcast beacon messages which include its information about its location. Each stationary sensor node takes the position as a beacon point and calculates its location by computing the intersection area of its communication coverage. After one round, localization of the unknown nodes can compute their location with help of localized node. [Baoli Zhang (2009)].

The research of G.Karthiga, C.Preethi and R.Delshi "Localization in Wireless Sensor Network Based on Mobile Anchor and Chord Selection" in 2014 discussed an approach of range-free technique through optimal path planning method for the mobile anchor used in the localization scheme. A single mobile anchor is used to enable the sensor nodes to construct two lines of a communication circle of which intersect at a certain point, the intersection of two lines is calculated in order to pointing the sensor positing. Path planning scheme in this study is specifically designed to both minimize the localization error and maximize the number of sensor nodes. [G.Karthiga (2014)].

1.4 Contributions

Sensor node positioning technology is a key enabling technology for wireless sensor networks (WSNs) in most applications. The position information of nodes is required in monitoring and tracking the target, routing is based on the position information. The accuracy of the position information is determined through localization. Often best performance of wireless sensor network come with a lowest localization error rate. This thesis focuses on two contributions to improve of the field of range-free localization technique in wireless sensor network. Firstly, the reduction of error rate (m) of localization technique and secondly, an improvement of the coverage of the sensing field of mobile node.

1.5 Introduction

Wireless Sensor Networks (WSNs) are spatially distributed autonomous sensors to monitor physical or environmental conditions as temperature, sound, pressure, etc. and their data to be cooperatively passed through the network to a main location. The more modern networks are bi-directional, and enabling the control of sensor activity. The development of wireless sensor networks which was motivated by military applications such as battlefield surveillance; these days such networks are used in many industrial and consumer applications, such as industrial process monitoring and control, machine health monitoring, and so on. [Graham Brooker (2007)].

The WSN is built of "nodes" from a few to several hundreds or even thousands, which means each node is connected to one (or some times

several) sensors. Each such sensor network node consists typically several components , as shown in Figure (4): a radio transceiver with an internal antenna or connection to an external one, a microcontroller, an electronic circuit for interfacing with the sensors and an energy source, usually a battery or an embedded form of energy harvesting. The cost of sensor nodes is similarly variable, ranging from a few to hundreds of dollars, which depends on the complexity of the individual sensor nodes, size and cost constraints on sensor nodes resulting in corresponding constraints on resources such as energy, memory, computational speed and communications bandwidth. [Graham Brooker (2007)].

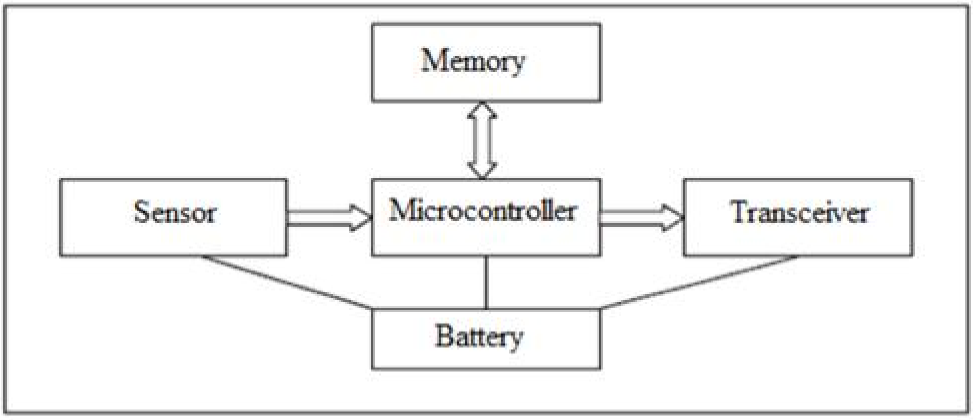

Figure 4 WSN node basic components. [Marco Zennaro (2012)]

1.6 Applications of WSNs

There are many applications that use wireless sensor networks in our daily lives; includes air monitoring, health care monitoring, air pollution monitoring, forest fire detection, land slide detection, water quality monitoring, natural disaster detection and industrial monitoring.

1.6.1 Health Applications

There has been a long history of using sensors in medicine and public health which is embedded in a variety of medical instruments for use at hospitals, clinics, and homes as sensors provide patients and their healthcare providers an insight into physiological and physical health states that are critical to the detection, diagnosis, treatment, and management of ailments. Much of modern medicine would simply not be possible nor be cost effective without sensors such as thermometers, blood pressure monitors, glucose monitors and various forms of imaging sensors. Emory A [9]. The ability to measure physiological state is also essential for interventional devices such as pacemakers and insulin pumps. Medical sensors combine transducers for detecting electrical, thermal, optical, chemical, genetic, and other signals with physiological

origin with signal processing algorithms to estimate features indicative of a person’s health status. Sensors beyond those that directly measure health state have also found use in the practice of medicine. For example, location and proximity sensing technologies are being used for improving the delivery of patient care and workflow efficiency in hospitals Figure (5) show application of sensors in hospital. [Emory A (2005)].

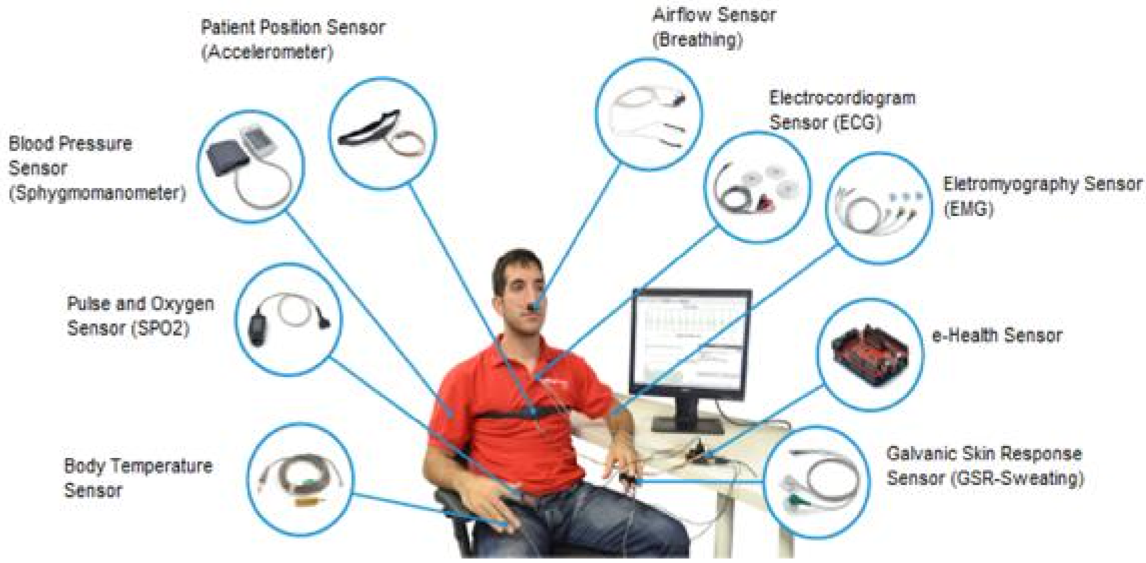

Figure 5 Application of sensors in hospital [www.cooking-hacks.com].

1.6.2 Military Applications

One of the main drivers for investigating wireless sensor networks is their use in military applications. The military use-cases for wireless sensor networks are diverse. They encompass many applications such as; monitoring militant activity in remote areas of specific interest (e.g., key roads, villages); force protection (e.g., ensuring that buildings which have been cleared remain clear from any infiltration by an adversary). One prominent use-case which has received a great deal of interest from military personnel recently has been base protection (or force protection in general). Figure (6) show Wireless sensor in support of military base protection. [Michael Winkler (2008)].

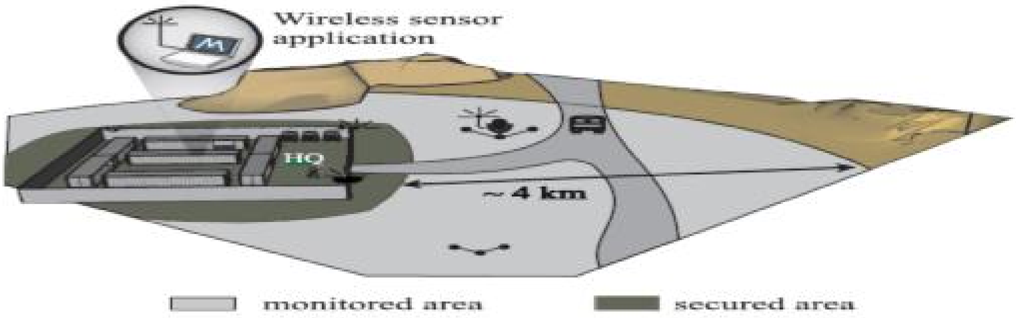

Figure 6 Wireless sensors in support of base protection [Michael Winkler (2008)]

When headquarters have been deployed in an area of an active engagement, it is essential to prevent the base from being attacked. The surrounding terrain may be undulating or mountainous and potentially could be obscured in trees and vegetation. Attack could come in the form of militant groups on foot or with motor vehicles. If an early detection to be facilitated the perimeter protection in Figure (6) would cover a belt around the camp of up to 4 km, while in practice it ranges of up to 10 km which might be a requirement. Detection may be needed throughout the whole range whilst identification may only be required within a belt of around 1–2 km around the base. [Michael Winkler (2008)].

1.6.3 Security Monitoring

Security monitoring networks are collected of nodes that are placed at fixed locations throughout an environment that continually monitor one or more sensors to detect an anomaly. A key difference between security monitoring and environmental monitoring is that security networks are not actually collecting any data. This has a significant impact on the optimal network architecture. Each node has to frequently check the status of its sensors, but it only has to transmit a data report when there is a security violation. The immediate and reliable communication of alarm messages is the primary system requirement. These are “report by exception” networks. It is confirmed that each node is still present and functioning. If a node were to be disabled or fail, it would represent a security violation that should be reported. [Kiran Maraiya (2011)]. For security monitoring applications, the network must be configured so that nodes are responsible for confirming the status of each other. One approach is to have each node be assigned to peer that will report if a node is not functioning. The optimal topology of a security monitoring network will look quite different from that of a data collection network. In a collection tree, each node must transmit the data of all of its decedents. The accepted norm for security systems today is that each

sensor should be checked approximately once per hour. Combined with the ability to evenly distribute the load of checking nodes, the energy cost of performing this check becomes minimal. A majority of the energy consumption in a security network is spent on meeting the strict latency requirements associated with the signaling the alarm when a security violation occurs. In security networks, a vast majority of the energy will be spend on confirming the functionality of neighboring nodes and in being prepared to instantly forward alarm announcements. Actual data transmission will consume a small fraction of the network energy[Kiran Maraiya (2011)].

1.7 Standards of WSN

1.7.1 Medium Access Control Protocol (MAC)

(MAC) protocols are the first protocol layer above the physical Layer (PHY) and consequently MAC protocols are heavily influenced by their properties. The fundamental task of any MAC protocol is to regulate the access of a number of nodes to a shared medium in such a way that certain application-dependent performance requirements are satisfied. Some of the traditional performance criteria are delay throughput, and fairness, whereas in WSN, the issue of energy conservation becomes important. [Linqing GUI (2013)].

Within the OSI reference model, the MAC is considered as a part of the Data Link Layer (DLL), but there is a clear division of work between the MAC and the remaining parts of the DLL. The MAC protocol determinesa node regarding the point in time when it accesses the medium to try to transmit data, control or management packet to another node (unicast) or to a set of nodes (multicast, broadcast). Two important responsibilities of the remaining parts of DLL are error control and flow control. Error control is used to ensure correctness of transmission and to take appropriate action in case of transmission error and flow control regulates the rate of transmission to protect a slow receiver from being overwhelmed with data. [Linqing GUI (2013)].

1.7.2 Standard IEEE 802.11 Wireless Fidelity (Wi-Fi)

Wireless Fidelity (Wi-Fi) is the technology based on IEEE 802.11 standard. It is mostly deployed for Wireless Local Area Network (WLAN) applications. A WLAN may either consist of stations running in ad-hoc mode (for example the new 802.11samendment), or it may consist of stations and access points (AP) in infrastructure mode. These two modes are distinguished by the use of an access point (AP). The AP can not only provide access to a wired LAN, but also organize the communications between stations in the same service area. The basic cell of a WLAN is called a Basic Service Set (BSS), which is a set of mobile

or fixed stations. If a station moves out of its BSS, it can no longer directly communicate with other members of the BSS. Based on the BSS, IEEE 802.11 standard employs the Independent Basic Service Set (IBSS) and Extended Service Set (ESS) network configurations. As shown in Figure (7), the IBSS operation is possible when IEEE 802.11 stations are able to communicate directly without any AP. Because this type of WLAN is often formed without pre-planning, for only as long as the WLAN is needed, this type of operation is often referred to as an ad hoc network. Instead of existing independently, a BSS may also form an extended form of network that is built with multiple BSSs.The architectural component used to interconnect BSSs is the distribution system (DS). The DS with APs allow IEEE 802.11 to create an ESS network of arbitrary size and complexity. This type of operation is often referred to as an infrastructure network. [Linqing GUI (2013)].

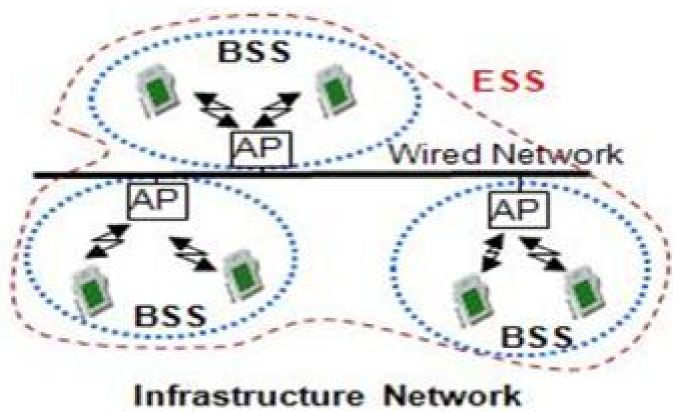

Figure 7 IBSS and ESS configurations of Wi-Fi networks [Linqing GUI (2013)]

1.7.3 Standard IEEE 802.15.4 Technology

IEEE 802.15.4 wireless technology is a short-range communication system intended to provide applications which are relaxed throughput and latency requirements in WPAN. The main features of 802.15.4 wireless technology are low complexity, low cost, low power consumption, low data rate transmissions and to be supported by either cheap fixed or moving devices. The main field of application of this technology is the implementation of WSNs**.** Reduced energy, against interference using Carrier Sense Multiple Access-Collision Avoidance (CSMA-Ca) and Guarantee Time Slots (GTS). Some technical details related to the physical and MAC layers as defined in this standard are reported. Finally, some characteristics related to higher layers will be presented, considering Zigbee, with particular attention to the former. The 802.15.4

core system consists of a radio frequency (RF) transceiver and the protocol stack as shown in Figure (8) [Chiara Buratti (2009)].

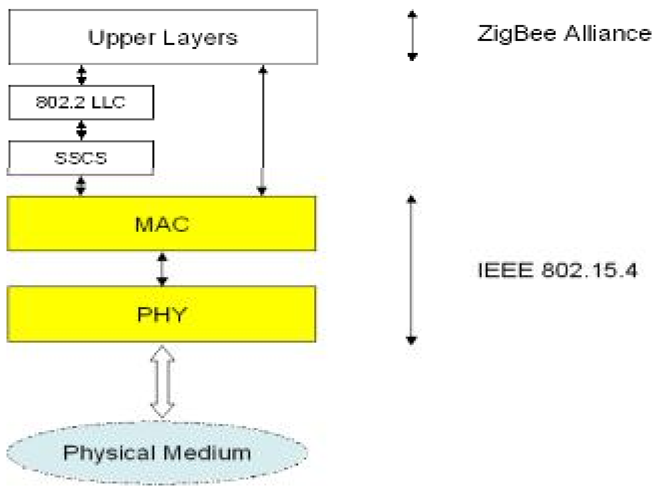

Figure 8 802.15.4 and ZigBee protocol [Chiara Buratti (2009)]

The 802.15.4 physical layer operates in three different unlicensed bands (and with different modalities) according to the geographical area where the system is deployed. However, spread spectrum techniques are wherever mandatory to reduce the interference level in shared unlicensed bands. IEEE 802.15.4 specifies a total of 27 half-duplex channels across the three frequency bands and is organized as below:

- The (868-868.6) [MHz] band: only a single channel with data rate 20 [kbps] is available.
- The (905-928) [MHz] band: 10 channels with rate 40 [kbps] are available.
- The (2.4-2.485) [GHz] with 5 [MHZ] spacing ISM band: 27 channels with data rate 250 [kbps] available.

The ideal transmission range is computed while considering that any legally acceptable power is permitted, IEEE 802.15.4 compliant devices are active only during a short time and the standard allows some devices to operate with both the transmitter and the receiver inactive for over 99% of time. [Holger Karl (2005)].

1.7.3.1 The Design Space of WSN

The design space of WSN is quite different from the one of wireless networks as shown in Figure (9). [Marco Zennaro (2012)].

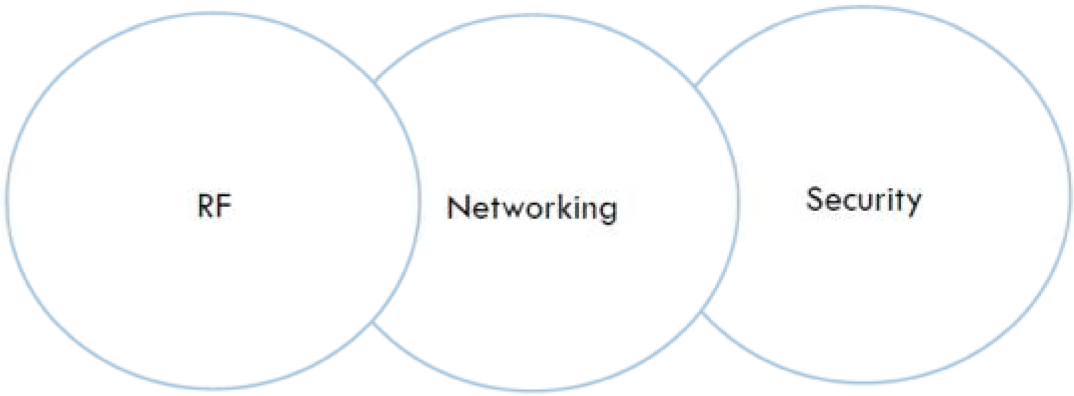

Figure 9 Design Space of WSN [Marco Zennaro (2012)]

Roles of participants in WSN. [Marco Zennaro (2012)]:

1- **Sources:** measure data, report them. Typically equip with different kinds of actual sensors.
2- **Sinks:** interested in receiving data from WSN, may be part of the WSN or external entity, PDA, gateway…etc.
3- **Actuators:** control some device based on data, usually also a sink.

1.7.4 ZigBee standard

This standard defines a communication layer at level 3 and above in the OSI model. Its main purpose is creating a network topology (hierarchy) to let a number of devices communicate among them and to set extra communication features such as authentication, encryption, and association and in the upper layer application services. It was created by a set of companies which form the ZigBee Alliance. ZigBee offers basically four kinds of different services. [Marco Zennaro (2012)]:

- Encryption services (application and network keys implementing extra 128b Advanced Encryption Standard (AES) encryption).
- Association and authentication (only valid nodes can join the network).
- Routing protocol: Ad Hoc On-Demand Distance Vector (AODV), a reactive ad hoc protocol has been implemented to perform the data routing and forwarding process to any node in the network.
- Application Services: An abstract concept called "cluster" is introduced. Each node belongs to a predefined cluster and can take a predefined number of actions. Example: the "house light system cluster" can perform two actions: "turn the lights on", and "turn the lights off".

1.7.5 6LowPan standard

In 2007 the Internet Engineering Task Force (IETF) has released an open standard called 6LowPAN Figure (10), in order to use IPv6 over 802.15.4. Abbreviation 6LowPAN stands for IPv6 over Low-Power WPANs. IP for Smart Objects (IPSO) Alliance is promoting the use of 6LowPAN and embedded IP solutions in smart objects. As Zigbee bottom two layers in 6LowPAN are the 802.15.4 layers. 6LowPAN is a protocol definition describing how to utilize IPv6 on top of low power, low data rate, low cost personal area networks. The charter of 6LowPAN working group is to define how to carry IP-based communication over IEEE 802.15.4 links while conforming to open standards and assuring interoperability with other IP devices. Some key technologies of 6LowPAN are as follows. [Ma.X.Luo (2008)].

- The coordination of IPv6 and IEEE802.15.4: by defining an adaptation layer, 6LowPAN compresses the 60 bytes long headers in IPv6 to 7 bytes and fragments the 1280 bytes long IPv6 packets to fit 127 bytes long 802.15.4 packets.
- Address assignment and management: one of the distinctive features of 6LowPAN is the capability of the dynamic assignment of 16-bit short addresses; by using this short address, hierarchical routing can be employed.
- Network management: As of the large scale of network and the distribution of place, LR-WPAN self-healing ability should be possessed, and LR-WPAN management technology is required to be able to manage highly dense deployment equipment with a very low expense.

6LowPAN is apt to use SNMPv3 (Simple Network Management Protocol) in LR-WPAN to progress network management.

The fundamental difference between 6LowPAN and Zigbee is the IP interoperability of the first. 6LowPAN devices are capable of communication with other IP-enabled devices whereas Zigbee node needs an 802.15.4/IP gateway to interact with an IP network. The decision to select one standard versus another should be determined by the target application. For an application in which there is no need to interface with IP devices or the packet size is small, it is not necessary to implement 6LowPAN, which performs fragmentation. Zigbee can achieve better overall performance in such an application. [Ma.X.Luo (2008)].

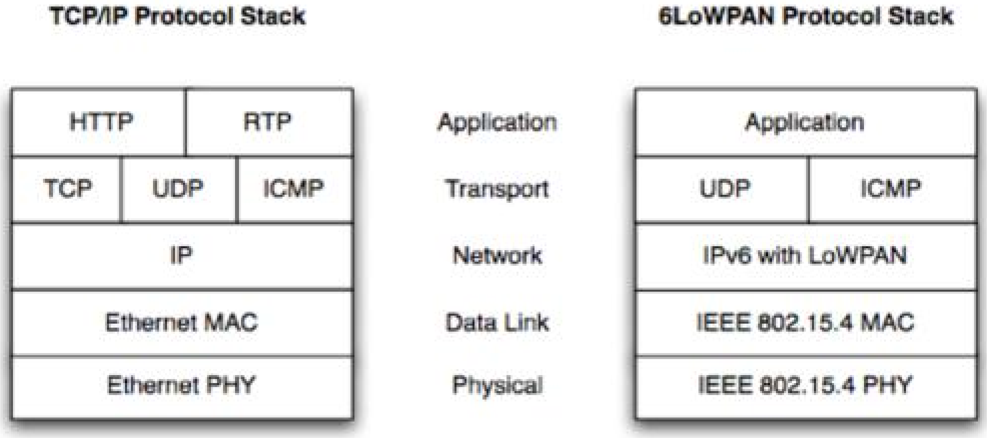

Figure 10 6lowPAN protocols [Ma.X.Luo (2008)]

Chapter 2
Localization and Positioning Techniques

2.1 Introduction

Localization is an important part in the field of wireless sensor networks attracted significant research interest recently. [D.Culler (2004)], [Jeril Kuriakose (2013)] The interest in wireless sensor network localization is always grow further with the advances in wireless communication techniques and sensing techniques, and the consequent reproduction of wireless sensor network applications. [I. F. Akyildiz (2005)], [Guobao Xu (2014)]. This chapter provides an overview of various aspects engaged in the design and enforcement of wireless sensor network localization systems. These can be generally classified into two categories, namely; wireless sensor network localization theory and algorithms and measurement techniques in wireless sensor network localization.

2.2 Properties of Localization and Positioning Techniques

The simple anticipation of "providing location information for a node" has a number of aspects that should be classified to make the options for a location procedure clear. Most of following properties are. [J.Hightower (2001)], [J.Hightower (2001)]:

2.2.1 Physical position against Symbolic Location

System provides data about the physical position of a node (in some numeric coordinate system) or does a node find out a symbolic location for example, living room, office number 421 in building 4?

In addition, possible to match physical position with a symbolic name (out of possibly several applicable ones)?

Two ideas are different, there is no consistent nomenclature in the literature – position and location are often used interchangeably. The tendency is to use "location" as the more general term. We have to rely on context to distinguish between these two contexts.

2.2.2 Absolute versus relative coordinates

An absolute coordinate system is available for all objects and embedded in some general frame of reference. For example GPS, positions in the Universal Transverse Mercator (UTM) coordinates form an absolute coordinate system for any place on world. Relative coordinates, on the other hand, can vary for any located object or set – a WSN where nodes have coordinates that are correct with respect to each other but have no relationship to absolute coordinates is an example.

To provide absolute coordinates, a few anchors are necessary (at least three for a two-dimensional system). These anchors are nodes that know their own position in absolute coordinate system. Anchors can shift, translate, and possibly scale a comparative coordinate system so that it coincides with absolute coordinate system. These anchors are commonly called "beacons".

2.2.3 Localized versus centralized computation

Any required calculations performed locally, by the unknown nodes, on the basis of some locally available measurements reported to a central station that calculates locations and distributes them back to other unknown nodes.

Privacy issues are important here as it might not be desirable for unknown nodes to reveal its position to a central entity in some application.

2.2.4 Accuracy and precision

The most two important figures for a localization system are the accuracy and the precision of its results. Positioning accuracy is largest distance between the estimated and true position of an entity (high accuracy point out a small maximal mismatch). Precision is the ratio with a given accuracy is reached, averaged over many repeated attempts to determine a position. For example, a system could claim to provide 20-cm accuracy with at least 95% precision. Clearly, accuracy and precision values only make sense when count together, forming accuracy/precision characteristic of a system.

2.2.5 Scale

A system can be designed for different scales, for example – in indoor deployment – size of a room or a building or – in outdoor deployment – monitor specific area or even worldwide operation. Two important figures here are the area the system can cover per unit of infrastructure and number of locatable objects per unit of infrastructure per time interval.

2.2.6 Limitations

For some positioning techniques, there are inherent deployment limitations. GPS, for example, does not work indoors: other systems have only limited ranges over which they operate.

2.2.7 Costs

Positioning systems cause costs in time (infrastructure installation, administration), space (device size, space for infrastructure), energy (during operation), and capital (price of a node, infrastructure installation).

Figure (11) illustrates the positioning problem. The figures in this chapter use the "access point" icon to indicate anchors for easy distinction. It should be pointed out, however, that sensor nodes can just as well be used as anchors, as long as they have are aware of their position.

In addition, a positioning or localization system can be used to provide the recognition or classification of objects; this property is less important in the WSN context or, if used, usually not considered a part of the localization system.

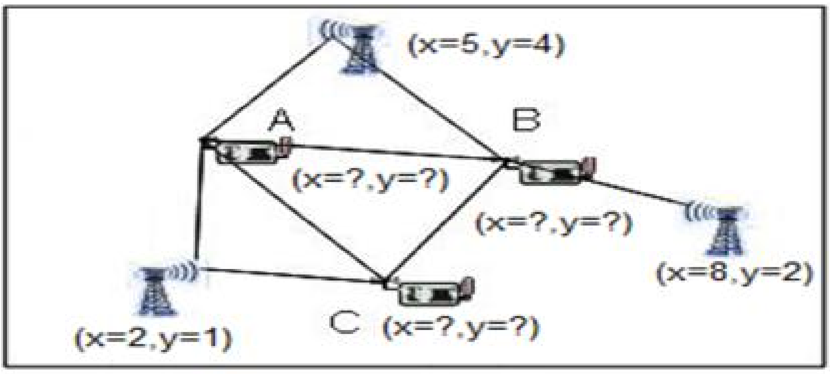

Figure 11 Determining the position of sensor nodes [Holger Karl (2005)]

2.3 Approaches

Three main approaches exist to determine a node's position; Using information about a node's neighborhood (proximity – based approaches), and trying to analyze characteristic properties of the position of a node in comparison with premeasured properties (scene analysis). The overview given here considerably follows reference [J.Hightower (2001)].

2.3.1 Proximity

The simple technique is to exploit the finite range of wireless communications. It can be used to decide whether a node that wants to determine its position is in the proximity of an anchor. While this only supplies coarse-grain information, it can be perfectly sufficient. [Holger Karl (2005)]. One example is the natural limitation of infrared communication by walls, which can be used to supply a node with simple location information about the room it is in.

Proximity-based systems can be quite developed and can even be used for approximate positioning when a node can analyze proximity information of several overlapping anchors. [N. Bulusu (2000)]. They can also be relatively robust to the suspicions of the wireless channel – deciding whether a node is in the proximity of another node is amounting to deciding connectivity, which can happen on comparatively long time scales, averaging out short-term variation.

2.3.2 Trilateration and Triangulation

In addition to mere connectivity/proximity information, communication between two nodes frequently allows to read out information about their geometric relationship. For example, the distance between two nodes or the angle in a triangle can be estimated using elementary geometry. This information can be used to split information about node positions when distances between structures are used, the approach is called lateration, or when angles between nodes are used, the approach is called angulation. [Bryant N. Sturgess (1995)], [Jeffrey Hightower (2001)].

For lateration in a plane, the simplest case is for a node to have summation distance measurements to three noncolinear anchors. The extension to a three-dimensional space needs four anchors. The following discussion will concentrate on the planar case for simplicity. Using distances and anchor positions, node's position has to be at the intersection of three circles around the anchors as shown in Figure (12).

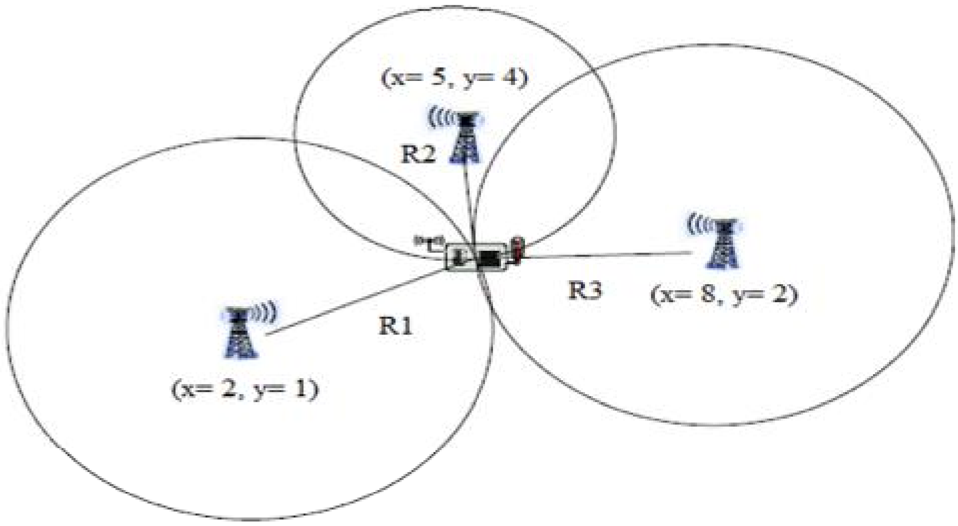

Figure 12 Trilateration by intersecting three beacon circles [Holger Karl (2005)]

The problem in reality, distance measurements are never perfect and the intersection of three circles will, in general, not result in a single point. To overcome these imperfections, distance measurements form

more than three anchors can be used, resulting in a multi-lateration problem. Multi-lateration is a core solution technique, used and reused in many solid systems described below. Its mathematical details are treated in Section (2.4) [Bryant N. Sturgess. (1995)].

Angulation take advantage of reality that in a triangle once the length of two sides and two angles are known, position of third point is known as intersection of the two remaining sides of triangle. Problem of imprecise measurements arises here as well and can also be solved using multiple measurements. [Jeffrey Hightower (2001)].

2.3.3 Determining Distances

To use multi-lateration, estimates of distances to anchor nodes are desired. This ranging process ideally leverages the facilities previously present on a wireless node, in specific, the radio communication device. Characteristics of wireless communication are parcel determined by the distance between the sender and the receiver, and if these characteristics can be measured at receiver.

They can serve as an estimator of distance. Most important characteristics are Received Signal Strength Indicator (RSSI), Time of Arrival (ToA), and Time Difference of Arrival (TDoA). [Guowei Shen (2008)].

2.3.4 Received Signal Strength Indicator RSSI

Assuming transmission power P_{tx}, path loss model, and path loss coefficient α are known, the receiver can use the received signal strength P_{rcvd} to solve for the distance d in a path loss equation. [C. Savvides (2002)]:

$$\text{(RSS) } P_{rcvd} = c\frac{P_{tx}}{d^{\alpha}} \leftrightarrow d = \sqrt[\alpha]{\frac{cP_{tx}}{P_{rcvd}}} \tag{2.1}$$

This is appealing since no additional hardware is necessary and distance estimates can be derived without additional overhead from communication that is taking place anyway. The disadvantage, however, is that RSSI values are not constant but can heavily oscillate, even when sender and receiver do not move. This is caused due to several effects, including; fast fading and mobility of the environment – ranging errors of ±50% are reported by SAVARESE et al. [C. Savvides (2002)]. To some degree, this effect can be counteracted by repeated measurements and filtering out incorrect values by statistical techniques. [A. Ward (1997)]. In addition, simple, cheap radio transceivers are often not calibrated and the same actual signal strength can result in different RSSI values on different devices. [K. Whiehouse (2002)]; similarly, the actual transmission power of such a transceiver shows discrepancies from the intended power. [A. Savvides (2001)]. A third problem is the presence of

obstacles in combination with multipath fading.[N. Bulusu (2001)]. Here, the signal attenuation along an indirect path, which is higher than along a direct path, can lead to incorrectly assuming a longer distance than what is actually the case. As this is a structural problem, it cannot be combated by repeated measurements. [V. Ramadurai (2002)].

A more detailed consideration shows that mapping RSSI values to distances is actually a random process. [RAMADIRAI and SICHITIU (2002], for example, collected, for several distances, repeated samples of RSSI values in an open field setup. Then, they counted how many times each distance resulted in a given RSSI value and computed the density of this random variable. Figure 13 (a) shows this probability density function for a single given value of RSSI, and Figure 13 (b) for several. The information provided in specific by small RSSI values, indicating longer distances, is quite limited as the density is widely spread.

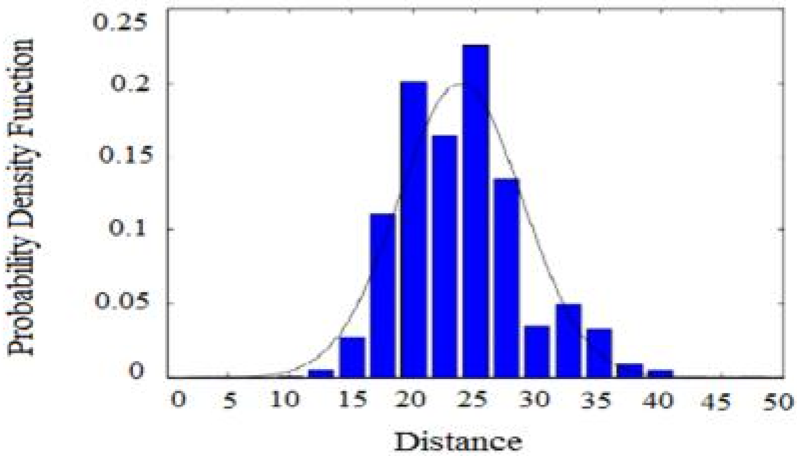

Figure 13 (a) (PDF) of distances resulting in a given RSSI values [V. Ramadurai (2002)]

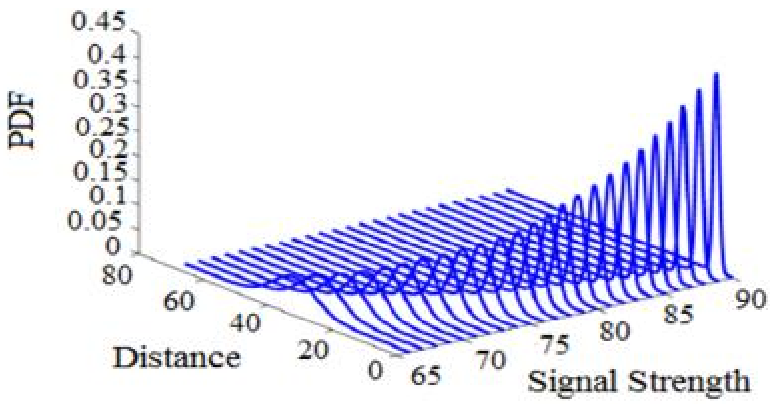

Figure 13 (b) Several (PDF) of distances for various given RSSI values [V. Ramadurai (2002)]

Figure 3.3(a and b) are Random nature of mapping RSSI values to distances. [V. Ramadurai (2002)].

Hence, when using RSSI as a ranging technique, it is necessary to accept and deal with considerable ranging errors or to treat the outcome of the ranging process as a stochastic result to begin with.

2.3.5 Time of Arrival

Time of Arrival (ToA) utilize the relationship between distance and transmission time when the propagation speed is known. Assuming both the sender and the receiver know the time when a transmission – for example, a short ultrasound pulse – starts, the time of arrival of this transmission at receiver can be used to compute propagation time and, thus, distance. To relieve the receiver of this duty, it can return any received "measurement pulse" in a deterministic time; the original sender then only has to measure the round trip time assuming symmetric paths.

Depending on the transmission medium that is used, time of arrival impose a very high resolution clocks to produce results of reasonable accuracy. For sound waves, these resolution requirements are modest; they are very hard for radio wave propagation. [Vladimir Savic (2015)].

2.3.6 Time Difference of Arrival

To overcome the need for explicit synchronization , the Time Difference of Arrival (TDoA) method utilizes implicit synchronization by directly providing the start of transmission information to the receiver. [Hailong Shi (2015)]. This can be done if two transmission mediums of different propagation speeds are used, for example, radio waves propagating at the speed of light and ultrasound, with different speeds of about six orders of magnitude. Hence, when a sender starts an ultrasound and a radio transmission simultaneously, the receiver can use arrival of the radio transmission to start measuring time until arrival of the ultrasound transmission, safely neglect the propagation time of the radio communication. The obvious disadvantage of this approach is need for two types of senders and receivers on each node. The advantage, on the other hand, is a considerably better accuracy compared to RSSI-based approaches. [N. B. Priyyantha (2000)].

2.3.7 Determining Angles

As an alternative to measuring distances between nodes, angles can be measured. Such an angle can either be the angle of a connecting line between an anchor and a position-unaware node to a given reference direction ("0° north"). It can also be the angle between two such connecting lines if no reference direction is commonly known to all nodes as shown in Figure (14).

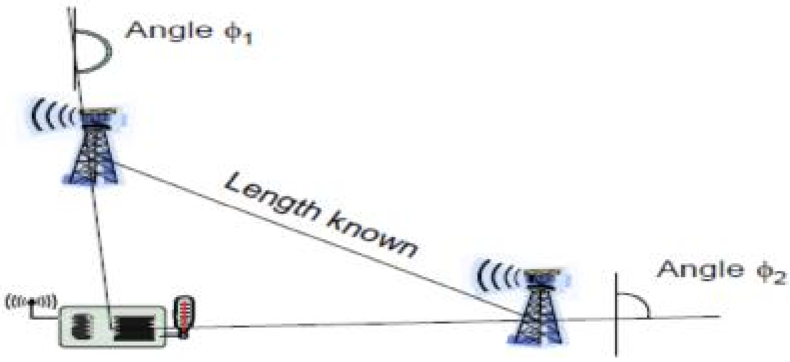

Figure 14 Angulation based on two anchors [Holger Karl (2005)]

A traditional approach to measuring angles is to use directional antennas that only send to/receive from a given direction, rotating on their axis, similar to a radar station or a conventional lighthouse. This makes angle measurements conceptually simple, but such devices are quite inappropriate for sensors nodes; they can be useful for supporting infrastructure anchors. [Jeffrey Hightower (2001)].

Another technique is to exploit the finite propagation speed of all waveforms. With multiple antennas mounted on a device at known separation and measuring time difference between a signals arrival at the different antennas, the direction from which a wave front arrived at the device can be computed. The smaller the antenna separation, the higher the precision of the time differences has to be, which result in strenuous timing requirements given the desirable small size of sensor nodes.

2.4 Mathematical modeling for lateration problem

Since multi-lateration is one of most popular techniques for positioning used in WSNs, and serves as a primitive building block for some of the approaches discussed later, it is worthwhile to have a closer look at the mathematics involved.

2.4.1 Solution with three anchors and correct distance values

Assume that there are three anchors with known positions (x_i, y_i), i = 1, …, 3, a node at unknown position (x_u, y_u), and perfect distance values ri, i = 1, …, 3. From the Pythagoras theorem, a set of three equations follows:

$$(x_i - x_u)^2 + (y_i - y_u)^2 = r_i^2 \text{ for } i = 1, \dots, 3. \qquad (2.2)$$

To solve this set of equations, it is more convenient to write it as a set of linear equations in x_u and y_u. To do so, the quadratic terms x_u^2 and y_u^2 have to be removed. This can be achieved by subtracting the third equations from the two previous ones, resulting in two remaining equations:

$$(x_1 - x_u)^2 - (x_3 - x_u)^2 + (y_1 - y_u)^2 - (y_3 - y_u)^2 = r_1^2 - r_3^2 \qquad (2.3)$$
$$(x_2 - x_u)^2 - (x_2 - x_u)^2 + (y_2 - y_u)^2 - (y_2 - y_u)^2 = r_2^2 - r_3^2 \qquad (2.4)$$

Rearranging of terms results in

$$2(x_3 - x_1)x_u + 2(y_3 - y_1)y_u = (r_1^2 - r_3^2) - (x_1^2 - x_3^2) - (y_1^2 - y_3^2) \quad (2.5)$$
$$2(x_3 - x_2)x_u + 2(y_3 - y_2)y_u = (r_2^2 - r_2^2) - (x_2^2 - x_3^2) - (y_2^2 - y_3^2) \quad (2.6)$$

Which can be easily rewritten as a linear matrix equation

$$2\begin{bmatrix} x_3 - x_1 & y_3 - y_1 \\ x_3 - x_2 & y_3 - y_2 \end{bmatrix}\begin{bmatrix} x_u \\ y_u \end{bmatrix} = \begin{bmatrix} (r_1^2 - r_3^2) - (x_1^2 - x_3^2) - (y_1^2 - y_3^2) \\ (r_2^2 - r_2^2) - (x_2^2 - x_3^2) - (y_2^2 - y_3^2) \end{bmatrix} \qquad (2.7)$$

Where the matrix on the left side and the right hand side only consists of known constants.

For example (Position determination) using the example positions of Figure (3.2) $(x_1, y_1) = (2, 1)$, $(x_2, y_2) = (5, 4)$, and $(x_3, y_3) = (8, 2)$ – with the distances between anchors and node of unknown position $r_1 = \sqrt{10}$, $r_2 = 2$, $r_3 = 3$, **Equation 2.7** becomes

$$2\begin{bmatrix} 6 & 1 \\ 3 & -2 \end{bmatrix}\begin{bmatrix} x_u \\ y_u \end{bmatrix} = \begin{bmatrix} 64 \\ 22 \end{bmatrix}, \qquad (2.8)$$

Resulting in $x_u = 5$ and $y_u = 2$ as the position of the unknown nodes.

2.4.2 Solving with distance errors

The real challenge for triangulation arises when the distance measurements are not perfect but only estimates $\check{r}$ with an unknown error ε are known. Solving the above equations with $\check{r} = r_i + \varepsilon_i$ will in general not yield the correct values for the unknown positions (x_u, y_u).

The intuitive solution to this problem is use more than three anchors and redundant distant measurements to account for error in each individual measurement. Mathematically, this turns the above equations into an over determined system of equations, written in matrix form as:

$$\begin{bmatrix} x_n - x_1 & y_n - y_1 \\ \vdots & \vdots \\ x_n - x_{n-1} & y_n - y_{n-1} \end{bmatrix}\begin{bmatrix} x_u \\ y_u \end{bmatrix} = \begin{bmatrix} (r_1^2 - r_n^2) - (x_1^2 - x_n^2) - (y_1^2 - y_n^2) \\ \vdots \\ (r_{n-1}^2 - r_n^2) - (x_{n-1}^2 - x_n^2) - (y_{n-1}^2 - y_n^2) \end{bmatrix} (2.9)$$

For such an over determined system of linear equation, a solution can be computed that minimizes the Mean Square Error (MSE), that is, the solution is the pair (x_u, y_u) that minimizes $\|Ax - b\|_2$, where 0.5A is the left-hand matrix

(an n – 1 x 2 matrix), x = (x_u, y_u) a shorthand for the vector describing the unknown position, and b the right hand side (an n-1 row vector) from **Equation (2.9)**.

Since $\|.\|_2$, the 2-norm of a vector (the square root of the sum of the squares of the vector elements), is minimized, this reflects solving for the position that best satisfies, with minimum average error, all the position constraints from all n anchors.

To find a solution for this minimization problem, look at an expression for the square of the 2-norm from above. Observe that for any vector (v), $\|v\|_2^2 = v^T v$. Hence,

$$\|Ax - b\|_2^2 = (Ax - b)^T(Ax - b) = x^T A^T Ax - 2x^T A^T b + b^T b \quad (2.10)$$

Minimizing this expression is equivalent to minimizing the mean square error. Regarding this as a function in x, its gradient has to be set equal zero:

$$2A^T Ax - 2A^T b = 0 \leftrightarrow A^T Ax = A^T b \quad (2.11)$$

Equation (2.11) is called the normal equation for the linear least squares problem. This equation has a unique solution under certain conditions (A has to have full rank). There are various methods to solve such an equation, for example, Cholesky or QR factorization (by substituting A = QR, Q an orthonormal and R an upper triangular matrix, directly into the normal equation and simplifying the resulting term), which differ in overhead and numeric stability (refer to any decent book on numerical mathematics for details). [Holger Karl (2005)].

For example (Positions with imprecise information) to illustrate this concept, look at the previous example, assuming that for the three anchors only incorrect position estimates $\tilde{r}_1$ = 5, $\tilde{r}_2$ = 1, and $\tilde{r}_3$ = 4 are available. Solving the resulting equation corresponding to Equation 9.7 gives the incorrect position (5.2,4.8) with a distance of $\sqrt{(5.2-5)^2 + (4.2-2)^2} \approx 2.2$ between estimated and correct position.

Adding additional anchors at (x_4 , y_4) = (3, 1), (x_5, y_5) = (7, 5), (x_6, y_6) = (2, 8), and (x_7, y_7) = (4, 6) with distance estimates $\tilde{r}_4$ = 2, $\tilde{r}_5$ = 3, $\tilde{r}_6$ = 7, and $\tilde{r}_7$ = 4, respectively should improve this estimate. The resulting matrix A and right hand side b are

$$A = \begin{bmatrix} 2 & 5 \\ -1 & 2 \\ -4 & 4 \\ 1 & 5 \\ -3 & 1 \\ 2 & -2 \end{bmatrix} \quad b = \begin{bmatrix} 56 \\ -4 \\ -16 \\ 30 \\ -29 \\ 17 \end{bmatrix} \tag{2.12}$$

Solving A^TAx = A^T b for x results in x = (5.5, 2.7), with a distance error of $\sqrt{(5.5-5)^2 + (2.7-2)^2} \approx 0.86$

Hence, this formalism allows computing of the position with the smallest mean square error out of n ≥ 3 anchors in the presence of errors in the distance measurements. The generalization to three dimensions is obvious. It is possible to extend this formalism even further when other parameters have to be estimated as well.

Chapter 3
Results and Discussions

3.1 Introduction

Wireless Sensor Network (WSNs) has been considered widely as one of the most important technologies of the twenty – first century. [Vishal Garg (2013)]. A WSN consists of a large number of small, low-cost, low-power and multi-functional sensor nodes that are deployed in a region of interest. [Jun Zheng (2009)], placed randomly and connected by wireless media to form a sensor field. Each node has special capabilities such as wireless communications with its neighbours, sensing, data storage and processing.

Since the most important process in WSN is localization, therefore, any solution proposed for localization must be accurate and efficient. To begin the localization, some sensor nodes with known locations are needed and are known as Anchor Nodes. The locations of these Anchor nodes can be determined by using a global positioning system (GPS). But using GPS equipment on all nodes is not realistic, as contrasted with WSN principles, a small -size, low- cost and low- energy for efficient sensing and communication. [Guibin Zhu (2010)], [Arthi (2010)].

The intersectional area of any two beacon node circles becomes smaller with the increase of the distance between their centers as shown in Figure (15). During localization, if sensor node S can find the farthest beacon points B1 and B2 in its reception range, we can get the smallest intersection area of the two beacon circles centered.

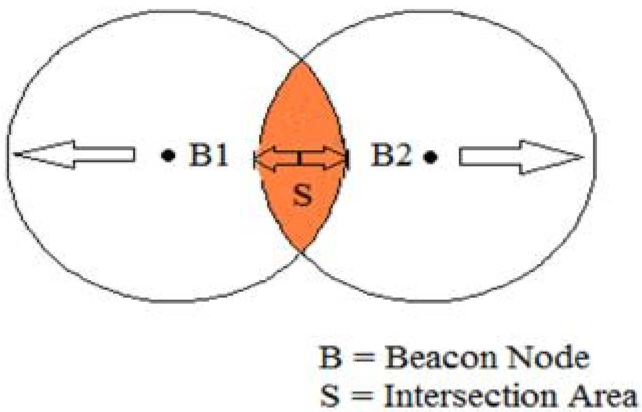

Figure 15 Intersection area of two beacon circles [Yu Liu (2012)]

In related work [Baoli Zhang (2009)]. "An Improved Localization Algorithm for Wireless Sensor Network Using Mobile Anchor Node". In this localization scheme two groups of beacon points to get a sensor location. The first group denoted B1and B2 at the first enters of mobile

anchor node in the field. The second group denoted B3 and B4 at the second enters of mobile anchor node in the field. The mobile anchor node moves with constant speed in straight line. In this way the mobile anchor node does not cover all the existing nodes in the field and the error rate of localization will be relatively high. [Baoli Zhang (2009)].

3.2 Centroid Localization Algorithm (CLA)

Centroid algorithm is first proposed by [Bulusu (2000)]. The basic principle is to regard the centroid point of neighbor anchors as the estimated position of the normal node. The author chooses a simple radio propagation model, which fits quite well for outdoor environment. The scenario is shown in Figure (16). In the network, there are totally *m* anchors situated at known position, $A_1(x_{1,}\, y_1), A_2(x_2, y_2)..A_m\ (x_m, y_m)$.

All these anchors have the same communication range denoted as *R*. Their transmission areas have an overlap, as shown by the shaded part in the figure. Inside the overlap locates the normal node N_x. That means, all these m anchors are the neighbor anchor of N_x.

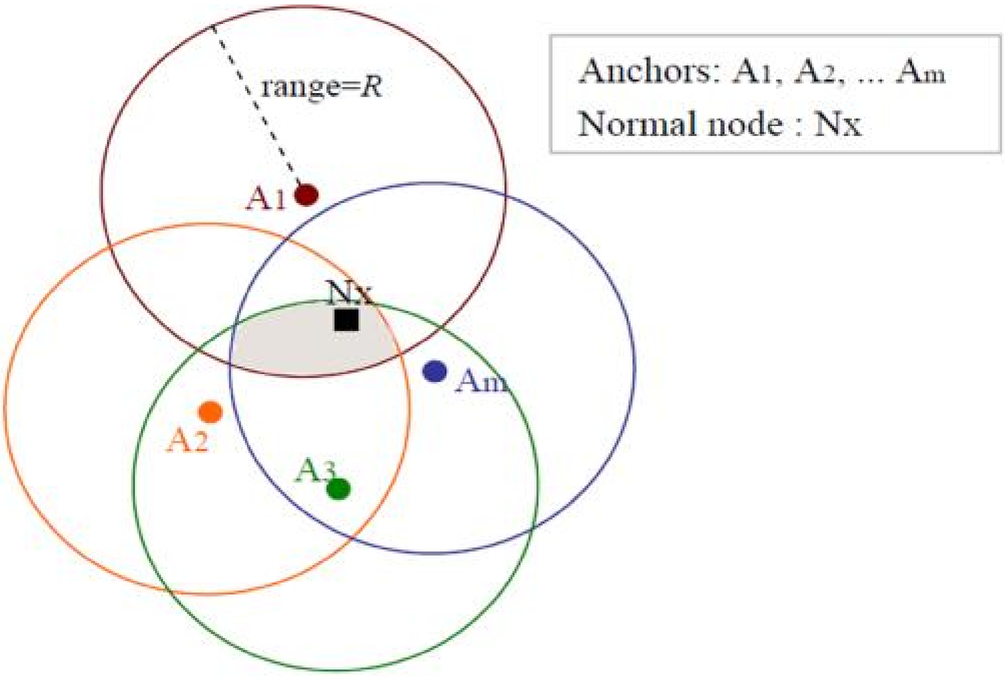

Figure 16 Centroid localization technique [Yu Liu (2012)]

Each anchor periodically (period=*T*) transmit one beacon message containing its position. [Bulusu (2000)] defined few terms list below:

R: Transmission range.

T: Time interval between tow beacon signals transmitted by anchor.

t: Normal node N_x use this time to collect beacon signals, (t > T).

N_{sent}(i, t): Number of beacon sent by anchorA_i, in time t.

N_{recv} (i, t): Number of beacon received by normal node in time t.

CM_i: Connectivity metric for anchor A_i.
CM_{thresh}: Threshold for CM.
(x_{es}, y_{es}): Estimated position of the normal node by the Centroid algorithm.
(x_{ac}, y_{ac}): Actual position of the normal node.

During the fixed time period t, the normal node N_x listens to the channel and collects all the beacon signals from various anchors. Although each anchor A_i has sent N_{sent}(i, t) signals, because of radio propagation interference, the normal node can actually receiveN_{recv} (i, t) signals from A_i . (Note that N_{recv} (i, t) ≤ N_{sent}(i, t)).

In order to know whether an anchor is really within the radio range of the normal node, the author defines connectivity metric for each anchor A_i, denoted as CM_i, [Bulusu (2000)]:

$$CM_i = \frac{N_{recv}(i,t)}{N_{sent}(i,t)} \tag{3.1}$$

In [Bulusu (20000], defines a threshold for CM_i , denoted as CM_{thresh} . If CM_i is larger than CM_{thresh} , the normal node N_x will regard the corresponding anchor A_i is neighbor to N_x. Therefore, when calculating position, N_x will take A_i into account. However, if CM_j is smaller than CM_{thresh}, N_x will see anchor A_j is not in its proximity, then N_x will not consider A_j when estimating its position. Assume that finally N_x can have k anchors whose connectivity metrics are larger than CM_{thresh}. These k anchors are $A_1, A_2, \dots A_k$. Then N_x localizes itself at the centroid of k anchors:

$$\begin{cases} x_{cen} = (x_1 + x_2 + \cdots + x_k)/k \\ y_{cen} = (y_1 + y_2 + \cdots + y_k)/k \end{cases} \tag{3.2}$$

In [Bulusu (2000)], estimates the accuracy of the Centroid algorithm by the metric localization error, which defined as:

$$\text{Localization error} = \sqrt{(x_{es} - x_{ac})^2 + (y_{es} - y_{ac})^2} \tag{3.3}$$

In [Bulusu (2000)], evaluates the algorithm performance by an experiment in a 10×10 m outdoor parking lot. 4 anchors are placed at the different corners. Their radio range is about 8.94 m. They transmit beacon signals containing their positions every 2 seconds (that means, T=2s). CM_{thresh} Is set to be 90%. Whenever the normal node moves to a new place inside the parking lot, it keeps static for 41.9s (that is t=41.9s),

receiving the beacon signals and finally calculating its position. As a result, the average location error is about 1.83m. [Bulusu (2000)].

Distance information used in CLA, there are two possibilities; either the unknown node is in the range of beacon radius or not. CLA acts from the assumption that each beacon has a circular area within it can communicate with other nodes. In the Figure (16), it is shown how the communication ranges of four beacons, arranged as described above, build up to several intersecting areas within an unknown can be localized. CLA uses the location information of all beacons in range to calculate the position as the centroid of the received beacon positions. [Yu Liu (2012)].

$$Ui(x, y) = \frac{1}{m} \sum_{j=1}^{m} Bj\ (x, y) \qquad (3.4)$$

In this formula, Ui(x, y) indicates the position of unknown i given by its two-dimensional coordinates. The known position of beacon j is given by Bj(x, y). The number of beacons which are within the communication range of the unknown node is indicated by (m). [Yu Liu (2012)].

Depending on the given calculation, a node which is situated within one of the intersecting areas will calculate its position at one single point, regardless of its exact position within the intersection area. For example, a node which is able to communicate to all of the four beacons will calculate its position in the center of the arrangement. As show in Figure (17).

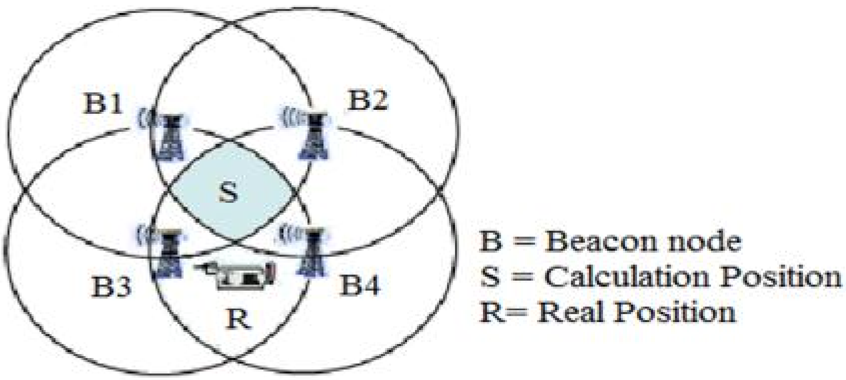

Figure 17 Calculated and real node position [Yu Liu (2012)]

However, former analysis of CLA mostly investigated the impact of the transmission range on the accuracy of the localization. [F. Reichenbach (2006)], [S. Schuhmann (2008)].

3.2.1 Improved Algorithm

In this section, we will present the extent of improvement localization accuracy for Wireless Sensor Network by using mobile anchor node with GPS receiver to obtain its position. The mobile anchor node moves around with specific trajectory in the sensor field to broadcast beacon messages which include its location information. Each stationary sensor node takes information from a beacon point and calculates its location by using centroid formula for four intersectional area of its communication coverage. After the first round localization, there might be a few sensors which are not covered by the mobile anchor node, the unknown nod sensor can compute their location with help of known nodes sensor.

The performance of the centroid algorithm utilized in the current model was assessed via MATLAB. In this model one hundred nodes are randomly deployed within a squared area with (100 m, 100 m), dimensions are as shown in the Figure (18). The mobile node anchor moves from initial point out of the sensing field with constant speed and specific trajectory until reach the destination point outside the field.

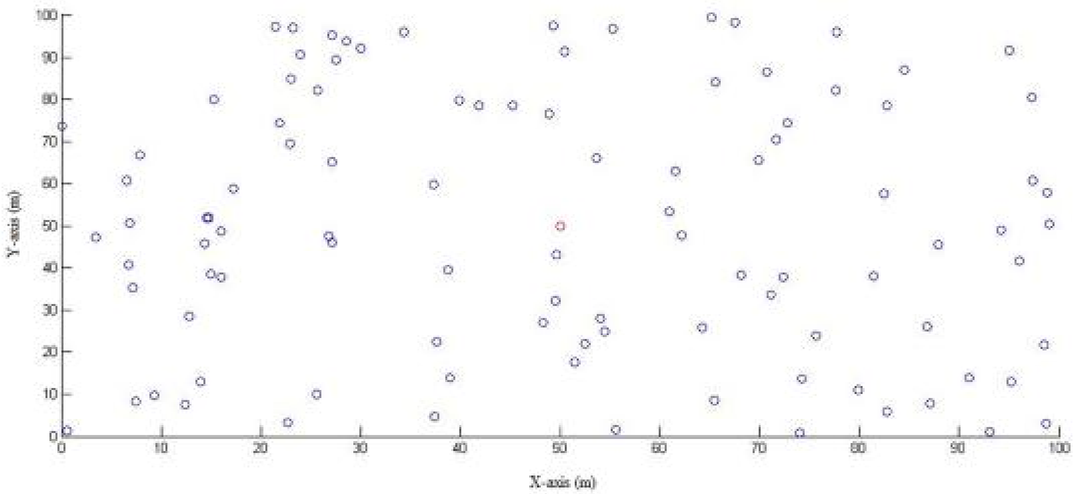

Figure 18 Randomly deployed Wireless Sensor Network

Mobile anchor node needs time T to do localization in this algorithm that can be summarized as follows:

1- The mobile anchor node selects an initial point and destination point outside of sensing field. Its moves from initial point to destination point with constant speed and with trajectory as shown in Figure (19). The mobile anchor node broadcasts beacon messages include information about location.
2- A stationary sensor node listens to the mobile anchor node and chooses beacon points to compute its location.

3- After a stationary sensor node has collected four beacon points which include two position messages where beacon are firstly received and two position where beacon messages are lastly received then its compute its location.

4- If stationary sensor node has not collected four beacon messages points, its broadcasts to localized neighbors to compute its location.

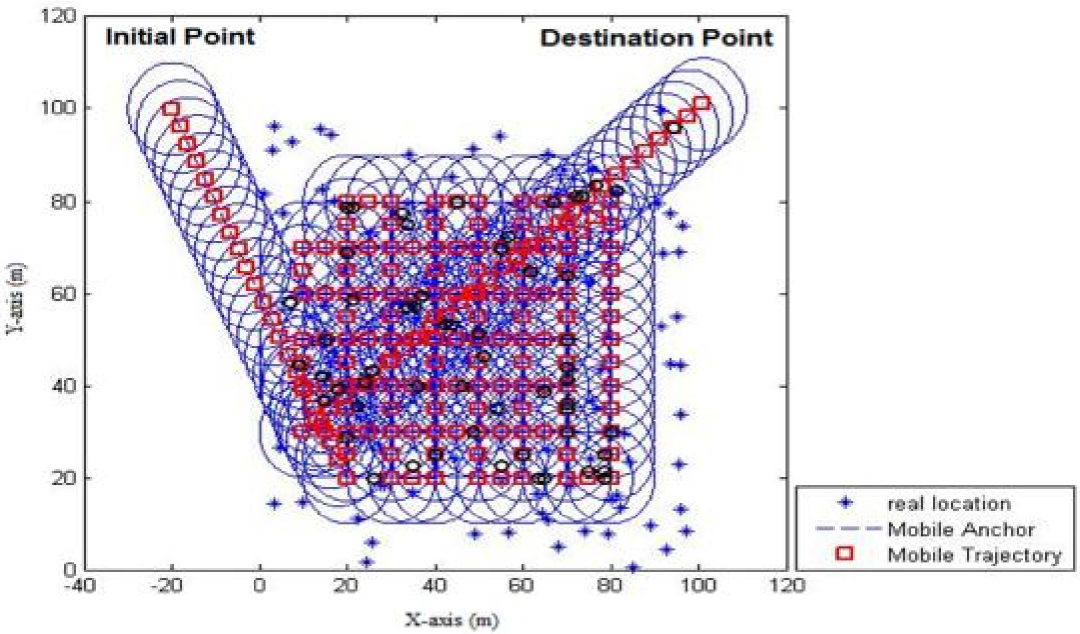

Figure 19 Trajectory of mobile anchor node

This analysis only done at fixed speed and radius of mobile anchor node verses different time interval, depend on range- free technique.

3.2.2 Location Calculations

After a stationary sensor node collects four beacon points, its location can be calculated by using centroid formula as shown in Figure (20). The coordinates of the four positions, B1, B2, B3, and B4 are $(x_1, y_1), (x_2, y_2), (x_{3,}y_3)$ and $(x_{4,}y_4)$, with communication radius R. Hence we can obtain the following equations:

$$\begin{Bmatrix} (x-x_1)^2 + (y-y_1)^2 = R^2 \\ (x-x_2)^2 + (y-y_2)^2 = R^2 \\ (x-x_3)^2 + (y-y_3)^2 = R^2 \\ (x-x_4)^2 + (y-y_4)^2 = R^2 \end{Bmatrix} \quad (3.5)$$

From equation (3.5) we can obtain four intersection points S1, S2, S3 and S4 and then we can use centroid formula to get the location of sensor node S.

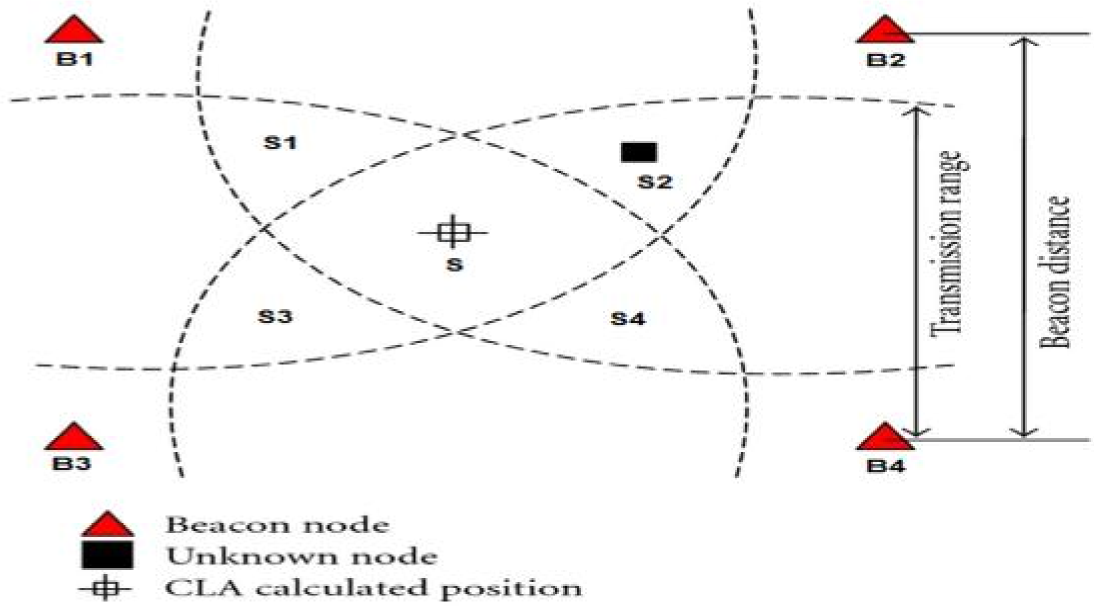

Figure 20 Calculation of a sensor location [Yu Liu (2012)]

Example 3.1

Calculation intersectional area for four circles with R=20 cm shown in the Figure (21).

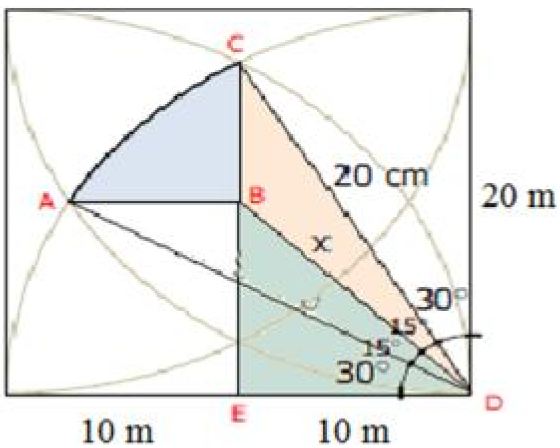

Figure 21 Intersectional area for four beacon circles [www.mathalino.com]

From triangle BED

Cos (30°+15°) = $\frac{10}{X}$

X= $\frac{10}{cos45°}$ = $10\sqrt{2}\ cm$

Area of sector ADC

$$A_{ADC} = \frac{\pi(20)^2\ (15^{\circ} + 15^{\circ})}{360^{\circ}} = \frac{100\pi}{3}\ cm^2$$

A_{ADC} = 104.72 cm^2

Area of triangle BDC

$A_{DBC} = \frac{1}{2}(20X)\sin 15^{\circ} = \frac{1}{2}(20)\left(10\sqrt{2}\right)\sin 15^{\circ}$

$$A_{DBC} = 36.60\ cm^2$$

Area of ABC

$A_{ABC} = A_{DAC} - 2\,A_{DBC} = 104.72 - 2(36.60)$

$A_{ABC} = 31.52\ cm^2$

$A_{required} = 4(A_{ABC}) = 4(31.52)$

$A_{required} = 126.08\ cm^2$ [43]. As show in Figure (22)

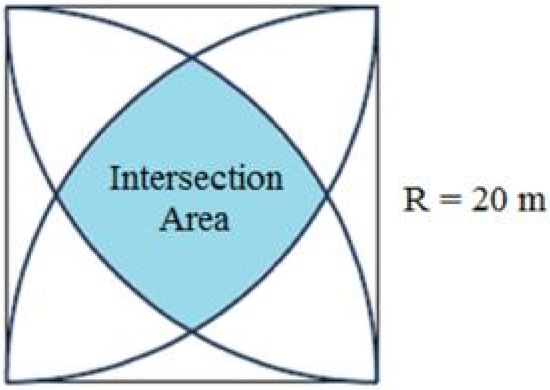

Figure 22 Required intersectional area [www.mathalino.com].

From the previous example by knowing the required size of the area we can calculate the center point of this region, and we note that whenever the radius of the circle increase the intersectional area will increase which leads to high error rate in the localization of the unknown node S.

Average localization error defined as the difference between estimated location (x_{ei}, y_{ei}) and actual location (x_i, y_i) of all sensors nodes. [K.F. Su (2005)].

$$\Delta E_{av} = \frac{\sum_{i=1}^{N}\sqrt{(x_{ei}-x_i)^2+(y_{ei}-y_i)^2}}{N} \tag{3.6}$$

Where N denotes the total number of stationary sensor nodes.

Average energy consumption is defined as the average energy used from sensor in wireless sensor networks based on protocols for communication. [María Gabriela (2006)].

$$P_{av} = \frac{\sum_{i=1}^{N} E_i}{N} \tag{3.7}$$

Where E_i denotes energy consumption of stationary sensor nodes i.

Average throughput is defined as the average rate of successful message delivery over a communication channel. [Flavio Fabbri (2011)].

$$R_{av} = \frac{\sum_{i=1}^{N} R_i}{N} \tag{3.8}$$

Where R_i denotes the throughput of stationary sensor nodes i.

3.2.3 Results

Figure (23) show the changes of localization error with increasing speed of mobile node. It is note the increase of the speed leads to increase localization error rate.

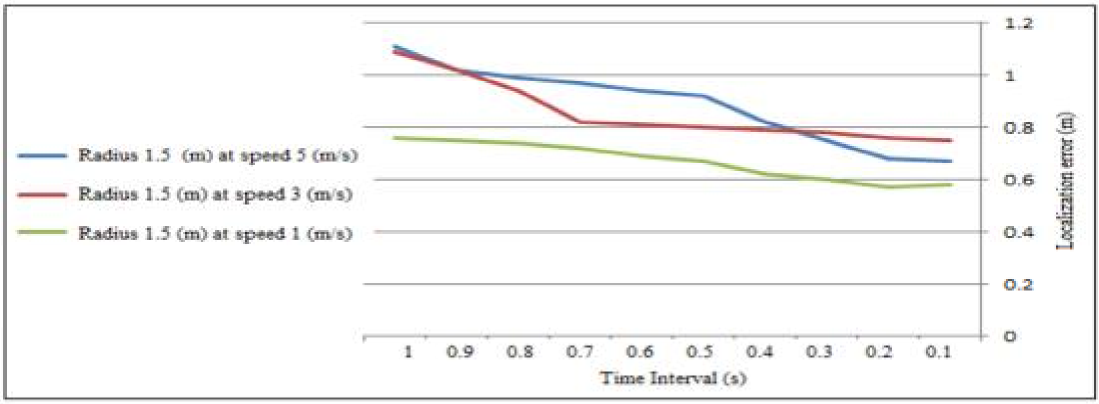

Figure 23 localization error versus anchor speed

Table (1) shows changing speeds of mobile node with same radius leads to a change in the margin of localization error for the results of several time intervals on MATLAB program. Keeping the radius fixed at (1.5m) and increasing the speed of a mobile node leads to increase in localization error rate.

Table 1 Localization error (m) at radius of (1.5m)

Speed m/s	Radius S	Packet Transmission Interval (sec)									
		0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
5	1.5	0.67	0.54	0.75	082	1	0.94	0.97	0.99	1.11	1.11
3	1.5	0.75	0.68	0.57	0.58	0.72	0.70	0.94	1.02	0.94	1.09
1	1.5	0.76	0.75	0.72	0.76	0.69	0.67	0.62	0.60	0.57	0.58

Figure (24) describes the relationship of localization error with time interval, and it is note that increase of time interval leads to increase of localization error.

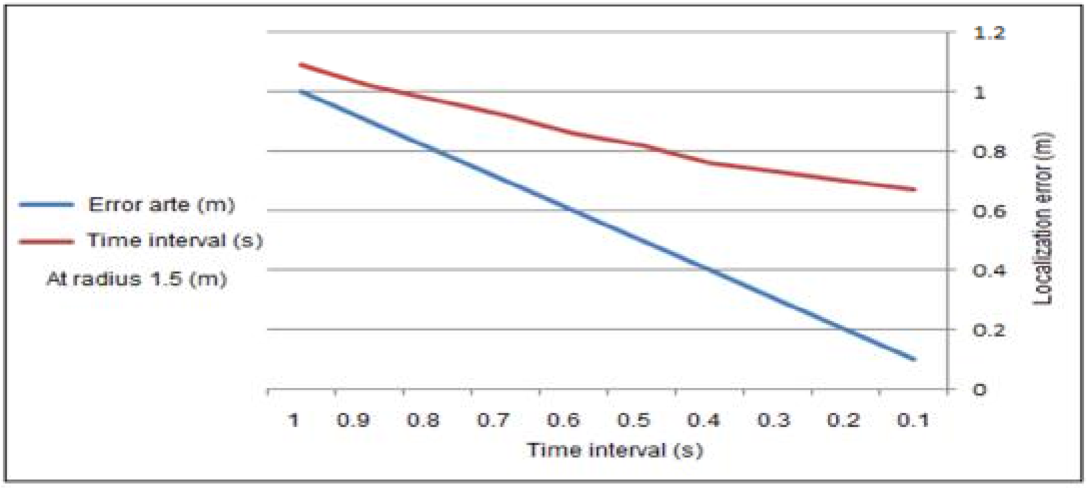

Figure 24 Localization error versus Time interval

Figure 25 (a) and Figure 25 (b) describes the relationship between constant speed of mobile node with changes of radius, it is note that increase of radius leads to increase localization error.

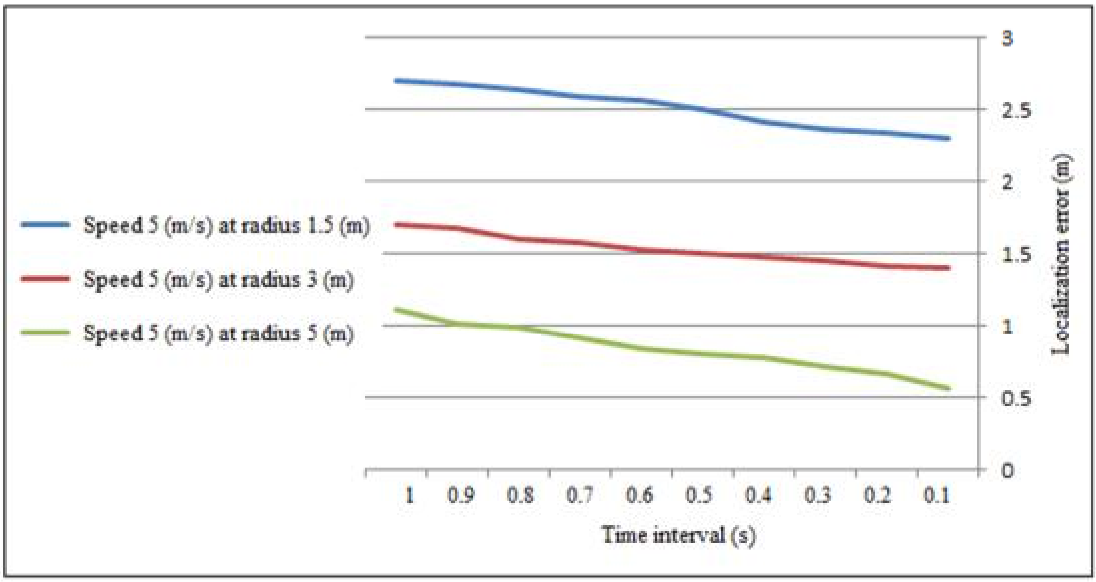

Figure 25 (a) Localization error versus radius

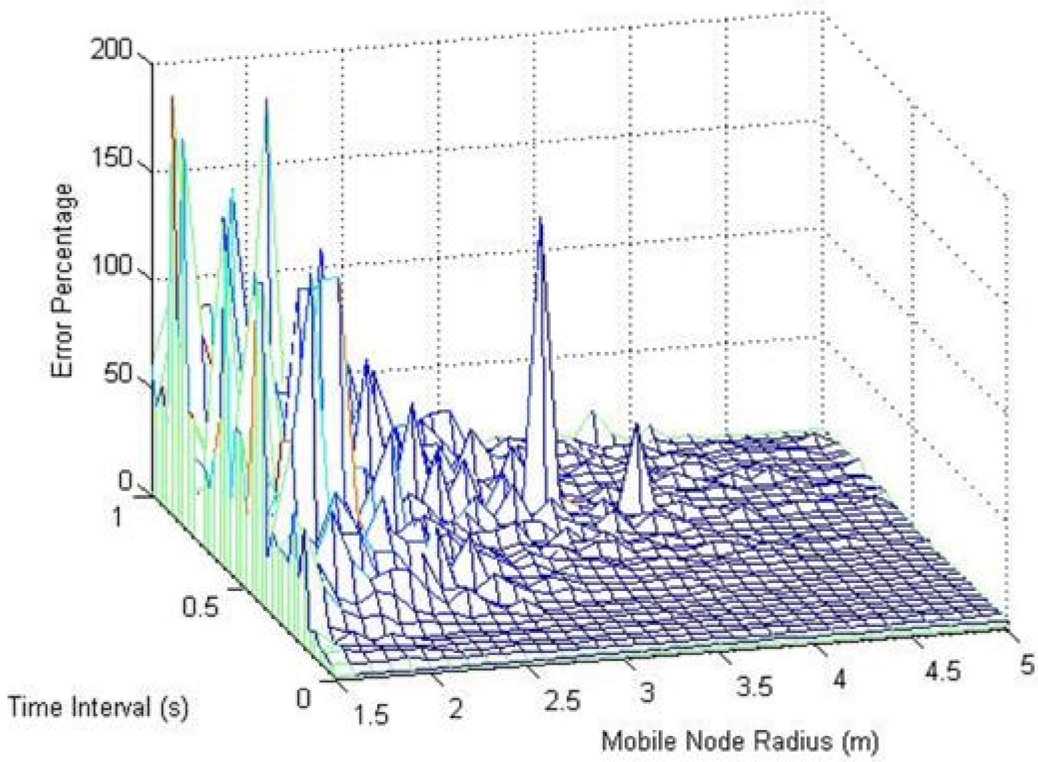

Figure 25 (b) Localization error versus radius

In previous localization algorithm, sensor location is computed based on beacon points selected recorded positions of mobile anchor node use centroid formula. Therefore time interval greatly affects localization accuracy, which is simulated and shown in table (2). The localization error of the proposed algorithm is less than of [Baoli Zhang (2009)].

Table (2) localization error comparison with different time interval

Time Interval	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
Thesis Result	0.67	0.54	0.75	0.84	1	0.94	0.97	0.99	1.11	1.11
Baoli Result	0.79	---	---	1.85	---	3.64	---	3.86	---	5.83

It is noted from the previous table (2) that the arithmetic average of the localization error rate (m) is equal:

$$\frac{0.79 + 1.85 + 3.64 + 3.86 + 5.83}{5} = 3.05$$

The results of thesis simulations arithmetic average localization error rate (m) are equal:

$$\frac{0.67 + 0.84 + 0.94 + 0.99 + 1.11}{5} = 0.91$$

And a proportion of the improvement is the difference between the previous research results and this thesis results is equal:

3.05 – 0.91 = 2.14 Average localization error (m) ratio for five time intervals.

Chapter 4
Conclusions and Future works

4.1 Conclusions

In this thesis, the foundation of wireless sensor networks localization was presented. The performances of any Wireless Sensor Network depend on most important factor is the accuracy of the proposed technique. Generally localization techniques in wireless sensor networks either; range-based or range-free.

This thesis relied on range-free technique. The most important technique in this area is the centroid algorithm which considers the intersectional area of two beacon nodes or more. It was noticed in the Simulations that greater number of intersectional area for beacon nodes reduce localization error rate (m) and the simulated node location become closer to reality.

Simulation results showed that use of centroid algorithm for four beacon nodes gave much less localization error than other range-free technique using mobile node. The proportion of the improvement was (2.14) ratio of average localization error (m) for five time intervals. The difference from the results of this thesis and the research conducted previously.

4.2 Future Works

There are many challenges such as choosing the best algorithm to calculate the localization of unknown nodes and finding the best trajectory for the mobile node anchor to cover most of unknown nodes in the sensing field area. This thesis focused on improving localization techniques in wireless sensor network only. It is recommended to so investigate the throughput in wireless sensor networks at greater distance than 100 meters area of sensing field and changing random distribution of unknown nodes to other distribution such as Gaussian distribution. Furthermore, unknown nodes may be grouped around a certain point which leads to facilitate the process of calculations in determining the locations of unknown nodes and reduces the load on mobile node.

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Appendix A
Simulation codes

```
function H=circle(center,radius,NOP,style)
if (nargin <3),
 error('Please see help for INPUT DATA.');
elseif (nargin==3)
    style='b-';
end;
THETA=linspace(0,2*pi,NOP);
RHO=ones(1,NOP)*radius;
[X,Y] = pol2cart(THETA,RHO);
X=X+center(1);
Y=Y+center(2);
H=plot(X,Y,style);
axis square;
clear all ;
close all;
clc;
%%% Improved Localization Algorithm %%%
% Stationary Sensors area
trans_interval = 1;
n_iteration = 10;
speed = 7; % m/s
X_s = 100; % meter
Y_s = 100; % meter
N = 100; % Number of stationary sensors
for n_it=1:n_iteration
N_sensors=N;
X = X_s *rand(1,N);
XX_s=X;
Y = Y_s *rand(1,N);
YY_s=Y;
plot(X,Y, '*')
x=[];
y=[];
%%%% Mobile Anchor Trajectory
X_m_in = -20;
Y_m_in = 100;
X_m_fin= max(X_s)+1;
Y_m_fin= max(Y_s)+1;
%plot(X_m_in, Y_m_in, 'sr','linewidth',2);
```

```
X_route = [10 10 10 10 10 10 10 20 20 20 20 20 20 20 30 30 30 30 30 30
30 40 40 40 40 40 40 40 50 50 50 50 50 50 50 60 60 60 60 60 60 60 70
70 70 70 70 70 70 80 80 80 80 80 80 80 70 60 50 40 30 20 10 10 20 30
40 50 60 70 70 60 50 40 30 20 10 10 20 30 40 50 60 70 70 60 50 40 30
20 10 ];
%X_m = [X_s*rand(1,3),X_m_fin];
X_m = [X_route ,X_m_fin];
Y_route = [80 70 60 50 40 30 20 20 30 40 50 60 70 80 80 70 60 50 40 30
20 20 30 40 50 60 70 80 80 70 60 50 40 30 20 20 30 40 50 60 70 80 80
70 60 50 40 30 20 20 30 40 50 60 70 80 70 70 70 70 70 70 70 60 60 60
60 60 60 60 50 50 50 50 50 50 50 40 40 40 40 40 40 40 30 30 30 30 30
30 30 ];
%Y_m = [Y_s*rand(1,3),Y_m_fin];
Y_m = [Y_route,Y_m_fin];
%hold on
%plot([X_m_in,(X_m)],[Y_m_in,(Y_m)],'--');
X = [X_m_in,X_m];
Y = [Y_m_in,Y_m];
Rad = 1; % communication radius
%plot([X_m_in,sort(X_m)],[Y_m_in,sort(Y_m)],'--')
for i= 1:(length(X)-1)
    ss=round((speed^-1 *
Euc_distance(X(i),Y(i),X(i+1),Y(i+1)))/trans_interval);
    b_x=linspace(X(i),X(i+1),ss);
    b_y=linspace(Y(i),Y(i+1),ss);
    x = [x b_x];
    y = [y b_y];
end
x_beacon = x;
y_beacon =y;
%hold all
%plot(x_beacon,y_beacon,'dr')
%  for p=1: length(x)
%      plot(x_beacon(p), y_beacon(p), 'sr','linewidth',2);
%      hold on
%      circle([x(p), y(p)],Rad,100,'-')
%      hold on
%      pause(0.1)
%      legend('real location','Mobile Anchor','Mobile
Trajectory','Location','NorthWestOutside')
%  end
%%% Localization - Phase #1
%% Find Beacon Points
```

```
sol= Beacon_point(XX_s,YY_s,x_beacon,y_beacon,Rad);
sensor_index=nonzeros(sol(:,1)) ;
beacon_index=nonzeros(sol(:,2)) ;
count_nodes=histc(sensor_index,unique(sensor_index)) ;
Sensor_table = [ unique(sensor_index)  count_nodes];
indexfourbeacons = Sensor_table(Sensor_table(:,2)>=3);
%figure
[X_est,Y_est]=estimate_location(indexfourbeacons,sol,x_beacon,y_beac
on);
%  plot(XX_s(indexfourbeacons),YY_s(indexfourbeacons), '*')
%  hold on
%  plot([X_m_in,(X_m)],[Y_m_in,(Y_m)],'--');
%  hold on
%  plot(x_beacon, y_beacon, 'sr','linewidth',2);
%  hold on
%  plot(X_est, Y_est, 'ok','linewidth',2);
 sum_E=0;
 for o=1:length(X_est)
     E=sqrt((X_est(o)-XX_s(indexfourbeacons(o)))^2+(Y_est(o)-
YY_s(indexfourbeacons(o)))^2);
      sum_E= sum_E+E;
 end
 Delta_E(n_it)=sum_E/length(X_est);
end
Error = mean(Delta_E)
plot(XX_s(indexfourbeacons),YY_s(indexfourbeacons), 'xr','linewidth',2)
hold on
plot(X_est, Y_est, 'ok','linewidth',2);
legend('Real location','Estimated location','Location','NorthWestOutside')
annotation('textbox',...
    [.3 .3 .4 .5],'String',{'Error ',['=' num2str(Error)]},...
   'FitBoxToText','on');
```

المعلومات الشخصية

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